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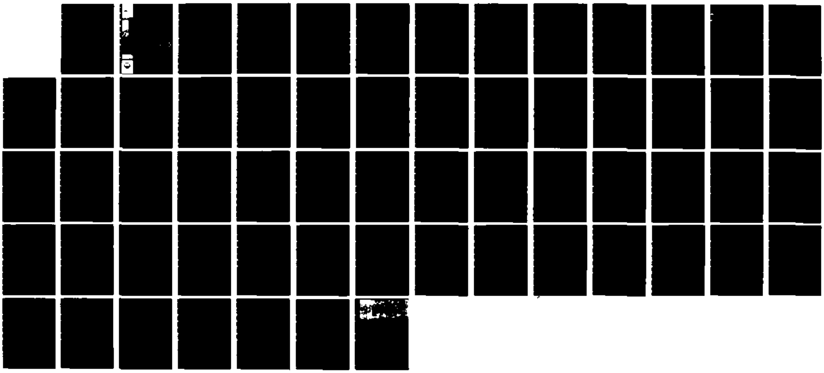

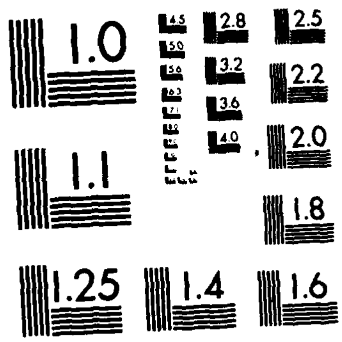

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NEARSHORE CURRENT MODEL WORKSHOP SUMMARY

by

Jon M. Hubertz

Coastal Engineering Research Center
U. S. Army Engineer Waterways Experiment Station
P. O. Box 631, Vicksburg, Miss. 39180

September 1983

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A program to improve and validate nearshore circulation models was begun in 1980 at the Coastal Engineering Research Center (CERC), then at Fort Belvoir, Va. The program's major objective was to develop the capability to predict currents and sediment transport in and near the surf zone.

One of the first goals of the program, to produce a state-of-the-knowledge review and an annotated bibliography, was accomplished upon publication of CERC reports MR 82-7(I) and MR 82-7(II). (Continued)

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20. ABSTRACT (Concluded).

A second goal, to use these reports as a basis for discussing (1) needed improvements in modeling nearshore currents and (2) future directions of research, was accomplished by means of a workshop held on 9-10 June 1982. Experts working in the field were invited to make formal presentations of current model studies and to participate in discussions to define improvements needed in (1) nearshore current theory, (2) nearshore current modeling, and (3) theory verification, i.e. instrumentation, measurements, and experiment design.

This report contains a general description of the workshop, a summary of the three working sessions, and author-provided abstracts of the formal presentations.

PREFACE

This report provides a summary of a workshop, held 9-10 June 1982, on the state of knowledge of nearshore current modeling. The U. S. Army Engineer Waterways Experiment Station (WES) Coastal Engineering Research Center (CERC) publications MR 82-7(I) and MR 82-7(II)--Surf Zone Currents, State of Knowledge, and Annotated Bibliography--were used as a basis for the discussions. The work was carried out under CERC's Nearshore Waves and Currents Work Unit, Harbor Entrances and Coastal Channels Program, Coastal Engineering ing Functional Area of Civil Works Research and Development. Technical Monitors from the Office, Chief of Engineers, for this program were Mr. John H. Lockhart, Jr., and Mr. John G. Houseley.

The report was prepared by Dr. Jon Hubertz, Coastal Oceanography Branch (COB), CERC, under the general supervision of Drs. C. L. Vincent and E. Thompson, former Chief and Chief, respectively, COB, Mr. R. P. Savage and Dr. J. R. Houston, former Chief and Chief, respectively Research Division, CERC, Dr. L. E. Link, Jr., Assistant Chief, CERC, and Dr. R. W. Whalin, P. E., Chief, CERC.

Commander and Director of WES during the publication of this report was COL Tilford C. Creel, CE. Technical Director was Mr. F. R. Brown.

CONTENTS

NEARSHORE CURRENT MODEL WORKSHOP SUMMARY

PART I: INTRODUCTION

1. Better techniques are required to estimate annual, seasonal, and storm-induced alongshore sand movement based on a description of nearshore waves and currents. The mean currents induced by wave and wind stresses in shallow water provide, in many instances, the major mechanism for transport of sediment, pollutants, and other constituents in shallow coastal waters. A satisfactory method to predict nearshore waves and currents and relate these to the movement of sediment along the coast and near structures does not exist.

2. The objective of a U. S. Army Engineer Waterways Experiment Station Coastal Engineering Research Center (CERC) 5-year research program, which began in 1980, is to develop methods for predicting wave- and wind-induced currents in and near the surf zone. To accomplish this objective, the theory of wave- and wind-generated currents is being investigated. A literature review and summary of state of knowledge* have been prepared and were used as starting points for the Nearshore Current Model Workshop held on 9-10 June 1982.

3. The agenda of the workshop (see Appendix A) was chosen to agree with the general topics addressed in the review summary of surf zone currents. These topics are the (a) physical description and (b) theoretical description of nearshore currents and (c) the experimental verification of theory.

4. An abstract of his formal presentation was provided by each speaker (see Appendix B) for inclusion in this workshop summary. These abstracts do not convey all the information exchanged in the presentation and the discussion sessions which followed. Part II of this report summarizes the sessions.

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* Basco, D. R. 1982. "Surf Zone Currents, Volume I: State of Knowledge," CERC Miscellaneous Report 87-2(I), U. S. Army Engineer Waterways Experiment Station, Vicksburg, Miss.

Basco, D. R., and Coleman, R. A. 1982. "Surf Zone Currents, Volume II: Annotated Bibliography," CERC Miscellaneous Report 87-2(II), U. S. Army Engineer Waterways Experiment Station, Vicksburg, Miss.

PART II: SUMMARY OF WORKSHOP SESSIONS

5. After the formal presentation, the attendees formed three groups to discuss in more detail the adequacy and direction of future work in the areas of nearshore current theory, modeling, and measurements. Individuals were free to contribute to each group as their interests dictated. The comments from each group as provided by the group leaders are summarized below.

Nearshore Current Theory

6. A sensitivity study needs to be done on the present best analytical models to single out important factors that require improved description. For example, better representations of bottom friction are needed, since model results are typically very sensitive to slight changes in bottom friction. Improvements could also be made in representing the following effects:

- a. The mechanics of the swash, or runup, zone.
- b. The influence of long-period waves (i.e., waves of 1-minute or more duration) on nearshore waves and currents.
- c. The incorporation of wave breaking in the Boussinesq theory.
- d. The representation of scattering, diffraction, and reflection of waves.
- e. Nonlinear wave theory.
- f. Realistic beach profiles.
- g. Random waves.
- h. Simplified three-dimensional flow structure.
- i. Improved boundary layer theory.

7. In addition, if changes were made in the theory of any of the above nine effects, a way to evaluate the new theory would be needed. It is suggested that a major three-dimensional laboratory investigation with an intense data collection effort be conducted. The laboratory experiment should allow for planar and nonplanar (barred and parabolic geometry) bathymetry, directional wave spectra, and the presence of coastal structures.

8. Experiments should be conducted in a large wave tank with a prototype scale, such as CERC's large wave tank, to investigate energy dissipation and turbulent transfer processes, as well as three-dimensional velocity profiles.

9. Field experiments should be conducted similar to the Nearshore Sediment Transport Study experiment,* but should include large angles of wave incidence, wind as a dominant forcing function, and nonplanar beach profiles.

Nearshore Current Modeling

10. Numerical models exist today which give acceptable qualitative answers to simple situations, but improvements can be made in a number of areas. The improvements most needed in application-oriented models are as follows:

- a. Computation of the wave climate in the interior of the grid, which would include refraction, shoaling, diffraction, reflection, dissipation, and wave-current interaction.
- b. Incorporation into models of wave-breaking.
- c. Parameterization of turbulence in models.
- d. Incorporation into models of surf zone energy dissipation.
- e. Methods to specify waves and currents on the boundaries of the grid.
- f. Incorporation into models of frictional processes.
- g. Methods for modeling periodic wave input.
- h. Methods for modeling spectral wave input.
- i. Methods for modeling complex bottom topography and structures.
- j. Three-dimensionality.
- k. Time-dependency.

11. It would also be desirable to have an intercomparison of models, with controlled data input to point out model differences. More coordination among model developers would speed improvements and allow the results of current research to be incorporated into application-oriented models; ideally, such models would be easy and economical to use and structured so that different models address different problems.

12. Models should be supported by good graphical and numerical data output. They also should be robust; i.e., relatively insensitive to and stable for various input data.

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* Gable, C. G. 1979. "Report on Data from the Nearshore Sediment Transport Study Experiment at Torrey Pines Beach...," IMR Reference No. 79-B, Institute of Marine Resources, University of California, La Jolla.

Instrumentation and Experiment Measurements

13. Instrumentation useful in measuring parameters in the nearshore zone has increased and improved in the past several years. For example, pressure gages and electromagnetic current meters are being used to measure waves and currents in the surf zone. However, the best one can hope for today in the validation of theory or model results is a qualitative consistency in patterns of flows or levels. To date there are no acceptable instruments to measure sediment transport in the surf zone.

PART III: ACKNOWLEDGEMENTS

14. The author gratefully acknowledges the contributions of all the individuals involved in organizing and carrying out the workshop. Special recognition goes to Mr. Michael Mattie, who was the principal investigator of the work unit supporting this effort before and during the workshop.

APPENDIX A: AGENDA

NEARSHORE CURRENT MODEL WORKSHOP
June 9 and 10, 1982

Wednesday, June 9

8:00	a.m.	Registration Continental Breakfast	Clayton Hall Front Desk Room 119
9:00		Introductory Remarks Michael Mattie Coastal Engineering Research Center	Room 119
9:15		Dr. Jon Hubertz Coastal Engineering Research Center *"Overview of the State of the Art in Nearshore Circulation Models"*	Room 119
10:15		Dr. Ole Madsen Massachusetts Institute of Technology *"Longshore Current Models for Monochromatic Waves"*	Room 119
11:30		Dr. Robert Dalrymple University of Delaware *"Theoretical Models for Nearshore Currents"*	Room 119
12:30	p.m.	Lunch	Room 110
1:30		Dr. E. B. Thornton Naval Postgraduate School *"Random Wave Forcing of Longshore Currents"*	Room 119
2:30		Dr. Herman Wind Delft Hydraulics Laboratory *"Delft Circulation Model"*	Room 119
3:45		Dr. James Houston Waterways Experiment Station *"Wave-Induced Current Calculations at Oregon Inlet, North Carolina"*	Room 119

Wednesday, June 9, 1982

5:30	p.m.	Wine and Cheese Reception	Clayton Hall Lobby
6:30		Dinner	Room 110
7:30 ff.		Hospitality Suite Open	106 Christiana Towers East

Thursday, June 10, 1982

8:00	a.m.	Breakfast	Room 110
9:00		Dr. David Aubrey Woods Hole Oceanographic Institution *"Surf Zone Measurements: Precision and Accuracy"*	Room 119
10:00		Participant Presentations	Room 119

Dr. G. M. Hecker
Old Dominion University

"Wind-Induced Nearshore Currents"

Dr. Philip Liu
Cornell University

"Finite Element Modeling of Breaking Wave-Induced Nearshore Currents"

James Kirby
University of Delaware

"Finite Difference Modeling of Nearshore Circulation"

Dr. Y. Peter Sheng
Aeronautical Research Associates of Princeton

"Turbulent Transport Model for Coastal Environments"

Dr. James Witting
Naval Research Laboratory

"Numerical Calculations of Waves in Shallow Water"

Thursday, June 10, 1982

11:15	a.m.	Introduction of Workshop Discussion Sessions Michael Mattie	Room 119
11:30		Lunch	Room 110
12:30	p.m.	Workshop Discussion Sessions Discussion Leaders Michael Mattie Todd Walton Jon Hubertz	Rooms 119 213 111
3:45		Concluding Plenary Session	Room 119

APPENDIX B: AUTHORS' ABSTRACTS

Overview of State of the Art in Nearshore Circulation Models

Jon Hubertz
Coastal Engineering Research Center, U. S. Army Engineer Waterways
Experiment Station

A program to improve and validate nearshore circulation models was started in 1980 at CERC. The major objective of the program is to develop a capability to predict currents and sediment transport in and near the surf zone. One of the first products of the program was a state-of-the-art review and annotated bibliography. This overview is based on that publication, and this workshop is being held to coordinate and plan future research on this topic.

The scientific study of nearshore currents began in 1919 when the qualitative relationships between waves, longshore currents, rip currents, and sediment transport were recorded. Theories to account for these relationships were introduced in the late 1940's; they were based on balances of energy or mass or momentum in the surf zone. Conceptually these theories were correct, but they lacked a proper representation of the momentum transfer by waves traveling through the surf zone.

This deficiency was remedied in the early 1970's with introduction of the radiation stress theory. This is qualitatively a momentum balance theory in which the gradient of radiation stress is balanced by bottom friction. Improvements to this theory over the last 10 years have consisted of improvements in the representation of the bottom friction term and introduction of a lateral eddy viscosity term. At present, models based on this theory give qualitatively acceptable answers to simple situations.

Further improvements are needed in collection of field and laboratory data for verification of theories and models, as well as in the theories and models themselves. The most needed areas of improvement are in calculation of the wave field in the nearshore region and description of the physics of wave breaking. A possible approach to improving representation of the wave field and its transformation to the breaking point is use of Boussinesq theory. Models which employ this theory resolve individual waves without time averaging but do not yet model breaking waves.

It is recommended that fundamental, long-range research be conducted to extend the Boussinesq theory into the surf zone. Continued refinement of

radiation stress models is also recommended. Improvements should include nonlinear and irregular wave effects and improved models of wave-breaking and wave energy dissipation in the surf zone.

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LONGSHORE CURRENT MODEL FOR MONOCHROMATIC WAVES

by

Ole Secher Madsen, R.M. Parsons Laboratory
Department of Civil Engineering
Massachusetts Institute of Technology
Cambridge, MA 02139

ABSTRACT

This presentation is concerned with the establishment of the equations governing wave-induced longshore currents. The mathematical formulation and physical interpretation of:

(1) The Radiation Stress
(2) The Time Averaged Bottom Shear Stress
(3) The Lateral Mixing

are discussed.

The basic Longuet-Higgins (1969) model is derived in a modified form. The assumptions underlying this analysis are discussed:

(1) The Small Angle of Incidence
(2) Small Longshore Velocity Relative to the Wave Orbital Velocity
(3) The Lateral Mixing Parameterization
(4) The Use of Linear Wave Theory to Describe the Wave Motion Within the Surf Zone

An extension of the Longuet-Higgins model to include some of the effects neglected in this model is presented. A general reference to this is Ostendorf and Madsen (1979). The extension of the Longuet-Higgins model includes:

(1) Effect of Finite Angle of Incidence
(2) Nonlinear Bottom Stress
(3) Nonlinear Wave Effects

The basic assumptions underlying the resulting model for wave-induced longshore currents are reviewed and future improvements are discussed.

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Theoretical Aspects of Nearshore Circulation

Robert A. Dalrymple
University of Delaware
Newark, Del. 19711

Introduction

The nearshore circulation, consisting of longshore and rip currents occurring perhaps periodically along a beach, can be generated by a number of mechanisms, some more prevalent in nature than others. In this brief review, these mechanisms are placed in three general categories, similar to Dalrymple (1978).

Theory

The depth- and time- (over a wave period) averaged forms of the conservation of mass and momentum equations can be written as

$$\frac{\partial\bar{\eta}}{\partial t} + \frac{\partial ud}{\partial x} + \frac{\partial vd}{\partial y} = 0$$

and

$$\frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} = - g\frac{\partial\bar{\eta}}{\partial x} - \frac{1}{\rho d}\left[\frac{\partial S_{xx}}{\partial x} + \frac{\partial S_{xy}}{\partial y} + \tau_{b_x} - \tau_{s_x}\right] + \frac{1}{\rho}\left[\frac{\partial\tau_{xx}}{\partial x} + \frac{\partial\tau_{xy}}{\partial y}\right]$$

$$\frac{\partial v}{\partial t} + u\frac{\partial v}{\partial x} + v\frac{\partial v}{\partial y} = - g\frac{\partial\bar{\eta}}{\partial y} - \frac{1}{\rho d}\left[\frac{\partial S_{xy}}{\partial x} + \frac{\partial S_{yy}}{\partial y} + \tau_{b_y} - \tau_{s_y}\right] + \frac{1}{\rho}\left[\frac{\partial\tau_{xy}}{\partial x} + \frac{\partial\tau_{yy}}{\partial y}\right]$$

where (u,v) are the offshore and alongshore horizontal mean currents, $\bar{\eta}$ is the set-up (set-down) of the water surface, $d = (h+\bar{\eta})$ is the total water depth, S_{xx}, S_{xy}, S_{yy} are the radiation stresses which are a function of the local wave height and direction, τ_s, τ_b are the surface and bottom shear stresses, and τ_{xx}, τ_{xy}, τ_{yy} are the lateral shear stresses. These equations have been solved

analytically in a few simplified cases but, in general, have to be solved numerically. Examination of these equations show that any longshore (y-direction) variation in wave height will cause longshore variations in the radiation stress gradients which drive the nearshore flow. Therefore, in order to classify types of nearshore circulation it is necessary to classify the means by which these longshore wave height variations occur.

Classifications

Class I - Boundary Interaction: Surely the most prevalent cause for nearshore circulation is the effect of non-uniform (in the y direction) offshore topography. The concentration of wave energy on certain portions of the beach versus others due to refraction has been proven to be an effective means to generate these currents (Bowen 1969 and Sonu 1972). Other examples are offshore sand bars and coastal structures, such as groins and breakwaters which might occur periodically along a beach. Most of the numerical models that have been developed to date are in this class.

Class II - Wave Interaction: The first theory for rip currents is a member of this class; this is the edge wave model proposed by Bowen (1969) and Bowen and Inman (1969). The synchronous interaction of the incident wave with an edge wave leads to periodic variations in wave height in the longshore direction. Subsequent studies (Guza and Inman 1975) have shown that this mechanism must be restricted to reflective beaches, where wave breaking is almost non-existent. Dalrymple (1975) generalized this theory to any synchronous wave trains. In the next several years, the influence of wave groups on the nearshore circulation will be more fully understood.

Class III - Instability Models: Like the Class II models, the instability mechanism can occur on a beach with no longshore variations in offshore topography. The models are developed by examining the following question: for normally incident waves, are there possible steady-state solutions other than an infinite uniform set-up with no attendant currents? Through perturbation techniques, Miller and Barcillon (1978) and Dalrymple and Lozano (1978) show that other modes may exist which have periodically occurring rip currents. These two models are based on different hypotheses, and neither has been verified experimentally. Recently, Kirby, Dalrymple and Bruno (1982) have examined the LEO data of the U.S. Army Coastal Engineering Research Center and have shown a propensity for the highly scattered data to behave similarly to the model of Dalrymple and Lozano. Hino (1974) has also produced nearshore circulation including the movement of the sediment.

Conclusions

Nearshore circulation models can be categorized conveniently into three classes. The difficulty arises in trying to ascertain the percentage of time that the mechanism of each class prevails, if at all. Further experimental and theoretical work is needed to resolve this issue as well as to make the models more sophisticated; i.e., to include any lateral mixing in the instability models.

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Longshore Currents Driven by Random Waves

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The on-offshore distribution of the mean longshore current due to random waves approaching obliquely to shore is described and compared with an extensive array of measurements at Leadbetter Beach, Santa Barbara, California. The simplest and most straightforward case is considered in which it is assumed the waves are stationary and the beach has straight and parallel contours. The time-averaged governing equation then simplifies to a local, alongshore balance of the on-offshore gradient of the wave-induced momentum flux integrated over depth (commonly referred to as the radiation stress and denoted S_{xy}) with the bottom shear stress, τ_b

$$\frac{\partial S_{xy}}{\partial x} = -\tau_b \tag{1}$$

The radiation stress is described using linear wave theory

$$S_{xy} = E\, C_g \cos\theta \frac{\sin\theta}{C} \tag{2}$$

where θ is the mean angle of wave approach for the very narrow band waves described by a mean frequency, $\bar{f}$, and random wave heights. The term

$$\frac{\sin\theta}{C} = \text{const} = \frac{\sin\theta_o}{C_o} \tag{3}$$

is derived by Snell's law of linear wave refraction. Substituting S_{xy} given by (2) into (1), and rewriting

$$\frac{\sin \theta_o}{C_o}\left[\frac{d}{dx} E\, C_g \cos \theta\right] = -\tau_b = \rho\, c_f\, \overline{|\vec{u}|V} \tag{4}$$

where the usual quadratic bed shear stress relation has been assumed. The term in the brackets on the lefthand side of (4) is recognized as the change in the onshore component of energy flux for straight and parallel contours.

The transformation of wave height distributions and energy dissipation from offshore to the beach are described by solving the energy flux balance equation

$$\frac{dEC_{gx}}{dx} = \langle\varepsilon_b\rangle \tag{5}$$

where the energy density E and group velocity C_g are described by linear theory, and $\langle\varepsilon_b\rangle$ is the ensemble-averaged dissipation due to wave breaking.

From the field data it is found that the wave height distributions are reasonably described by the Rayleigh pdf, p(H), even at breaking. The waves after breaking take on various heights and, thus, will also have a distribution. It is assumed the broken waves will have diminished heights in proportion to the Rayleigh distribution, such that the breaking wave height distribution is defined

$$p_b(H) \equiv A_b\, p(H) = 2\frac{H}{H_b^2}\, e^{-\left(\frac{H}{H_{rms}}\right)^2} \tag{6}$$

A_b is the percent of broken waves which was determined from the analysis to be $A_b = (H_{rms}/H_b)^2$.

The energy dissipation due to wave breaking is described as that due to a periodic bore, where for the ensemble average

$$\langle \varepsilon_b \rangle = \frac{1}{4} g \bar{f} \frac{1}{h} \int_0^{\infty} H^3 p_b(H)\, dH = \frac{3 \sqrt{\pi}\, \rho g \bar{f}}{16 \alpha^2 h^3} H_{rms}^5 \tag{7}$$

where α is the only unspecified parameter to be determined using data.

Substituting (6) and (7), (5) can be solved analytically for a plane sloping beach, or numerically for arbitrary bottom profiles. The dissipation function from (5) is then substituted into (4) and the longshore current determined. The predicted longshore currents compare favorably with longshore currents measured at Santa Barbara.

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RIPCEL: A NUMERICAL MODEL FOR UNSTEADY WIND- AND WAVE-DRIVEN COASTAL CURRENTS

by

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Introduction

The numerical model RIPCEL is based on the 2-D depth-averaged Navier-Stokes equations. The currents are driven by breaking waves and/or by wind.

The model is constructed for the following purposes:

a study of the formulation and importance for the flow pattern of processes such as horizontal momentum exchange, bottom friction, convective terms, and radiation stress

b study of unsteady water motion; for instance, ripcurrents

The development of the model is well underway, and various tests have been carried out.

Numerical aspects

RIPCEL is an implicit finite difference model. The solution routine is based upon splitting the equations into x and y parts, which are treated alternately by a one-dimensional implicit process.

The grid is generated in such a way that one set of the gridlines remains straight. The other set of gridlines is made to fit the shoreline, the breakerline, and seaward boundary. Intermediate gridlines are obtained by interpolation. The second set of gridlines can be curved.

The shoreward boundary in shallow water of a depth of, say, 2 cm is treated as a vertical wall. The seaward boundary is low-reflecting.

Applications

RIPCEL has been applied for the following test conditions:

a wave set-up

b longshore currents on an infinite long straight beach (Longuet-Higgins, 1970)

c coastal circulations due to longshore variation in waveheight (Bowen, 1969)

d wave-driven currents in closed basins

e currents around groins

During the conference, results of the testcases mentioned above will be presented.

Conclusions

The following are preliminary conclusions:

1 Tracking of errors in the implicit scheme is time-consuming.

2 In the area where waves are not breaking, the numerical viscosity can easily be of the same order of magnitude as the physical viscosity.

3 For the development of RIPCEL, data of nonuniform current systems are essential.

4 For practical application of the present model for a barred coast, the definition of the boundary condition may cause a problem.

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Wave-Induced Current Calculations at
Oregon Inlet, North Carolina

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The Waterways Experiment Station (WES) has developed a wave-induced current numerical model as part of a program to develop a nearshore processes numerical modeling system to evaluate the impact of a proposed jetty construction project at Oregon Inlet, North Carolina. The model employs an alternating-direction implicit finite difference scheme to determine wave-induced currents and setup. A spatially varying computational grid is used that allows grid cells to be concentrated in areas of interest (e.g., surf zone or inlet). The equations that are solved include terms for advection, lateral diffusion, and friction.

Application of wave-induced current models to real prototype situations is difficult because of bathymetric and shoreline complexities and the large spatial size of typical areas of interest. For example, at Oregon Inlet bathymetric contours in the region of the ebb flow delta are almost at right angles to both the shoreline and typical contours distant from the inlet. An area of interest of approximately 150 km^2 was required to be covered by the numerical grid, and grid cell sizes as small as 30 meters were necessary in order to properly resolve transport in surf zone regions. Furthermore, simulations of an entire year were needed. Thus, it was necessary to develop a very stable model that also was efficient computationally. The resulting model requires very modest computational time to solve for wave-induced currents on a 5,000-point grid covering the Oregon Inlet area.

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SURF ZONE MEASUREMENTS: PRECISION AND ACCURACY

by David G. Aubrey

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INTRODUCTION

With recent advances in the theory and modeling of nearshore sediment transport, increased emphasis has been placed on accurate, high-quality field measurements with which to evaluate the various theories and models. A recent effort in this direction was the Nearshore Sediment Transport Study (NSTS), funded primarily through the National Sea Grant Office. Emphasis on large, well-funded programs reinforces the need for acquisition of good data sets for nearshore research studies. The design of these field studies immediately raises questions about the resolution and accuracy of instrumentation used in nearshore research.

The primary instruments used in nearshore field research are pressure sensors, wave staffs, some type of instrument to estimate sand movement on a net or gross basis, and current sensors (current meters). Technology for pressure sensors and wave staffs has advanced to a degree that accurate measurements are routinely made of sea surface elevation, with appropriate care and calibration. Sediment transport monitors are in an early developmental stage and have highly variable or unknown accuracies. Current measurement is a more refined art than sediment transport measurement, but it is not as well developed as pressure sensors or wave staffs. These current sensors are the subject of the present discussion.

The nearshore environment places stringent demands on any instrumentation located within it. Current meter systems as well as other types of instrumentation must be rugged and reliable, withstanding not only the impact associated with energetic breaking waves, but also maintaining calibration accuracy for relatively long periods of time. Especially in this difficult research environment, it is important to have instruments which have well known calibrations and associated uncertainties, as well as instruments which will have insignificant change in that calibration over a period of time. Without instruments satisfying these criteria, it is impossible to acquire data sets which are of sufficient quality to be usable in comparing and validating nearshore current models and nearshore sediment transport models.

One type of current meter in common use for nearshore current studies, primarily because of its ruggedness and low cost, is the electromagnetic current meter. This is the most common current meter used in the Nearshore Sediment Transport Study (Cunningham et al., 1979), as well as in studies proposed by the Coastal Engineering Research Center (CERC) in the near future. Because of time and funding constraints, most use of these current meters has not included thorough pre- and post-calibration to document the performance of these systems. In the nearshore environment, these sensors are subjected to combined steady and oscillatory flow fields. The behavior of the current meter in these combined flows is a function of the boundary layer structure developing under these flow fields. The boundary layer can be predicted for certain configurations of the electromagnetic current meter either theoretically or empirically, but complete and thorough testing of these systems is not generally available.

Although current meter performance in the laboratory is not an exact duplication of current meter performance in the field (in spite of attempts at dynamic similitude), laboratory calibrations are the best method available for assessing current meter performance. Alternative assessments generally involve the availability of a well-tested, highly accurate current meter against which to compare performance. Not only is such an instrument not available for surf zone use at the present time, but this method also is difficult to employ in the field. Because of this lack of alternative, the laboratory evaluation provides a good indication of field performance of current meter systems. Experience to date by the author supports this contention, in that direct field evidence has shown that laboratory calibrations are indeed good indicators of current meter performance in the field.

CALIBRATION STRATEGY

Basic Theory -- The different current measurement systems shown here employ electromagnetic flow meters. The principle of their operation has been treated in detail elsewhere (Longuet-Higgins, 1947; Shercliff, 1962; Bevir, 1970; and Cushing, 1976). The devices measure the flow of a conducting fluid past a sphere of a given diameter which has surface irregularities. Four irregularities are co-planar electrodes which protrude past the sphere surface about 5-10 mm, while the two remaining irregularities form the support cylinder (sting) along a line at right angles to the plane of the electrodes. The two sensing spheres used in this study have diameters of 10.6 cm and 3.8 cm, with respective electrodes protruding 1.0 cm and 0.5 cm about the surface of the sphere, and respective support cylinders of 2.5-cm and 0.95-cm diameters.

In elementary terms, steady flow around a sphere varies as a function of Reynold's number (Re). At low Re, flow around the sphere is laminar, and a laminar boundary layer develops. As Re increases, the flow becomes turbulent, and the point of flow separation migrates further downstream from the laminar case. Critical Reynold's number for transition to turbulence over a smooth sphere is approximately 2-4 x 10^5. For flow past a sphere with protrusions, the boundary layer is tripped at a lower Re, whose value must be determined empirically depending on the specific geometry. Similarly, if the ambient flow field is turbulent on a scale comparable to sphere diameter, the transition Re can be significantly reduced. Note that separated flow occurs even with laminar conditions if Re $>10^2$. For a smooth sphere, the separation point is further downstream for turbulent flow (>120°) than for laminar flows (110°) from stagnation point (Landau and Lifschitz, 1959; and Schlichting, 1968).

Boundary layer thickness also varies in the downstream direction, increasing from the stagnation point. Turbulent boundary layer thickness is in general greater than laminar boundary layer thickness. Cushing (1976) describes the effects of boundary layer thickness on calibration results and on the variation in current meter gain.

Generally, to obtain a roughly linear calibration over a broad range of velocities (or Re), the boundary layer is tripped so turbulence occurs at a lower Re than for the smooth-body case. This tripping can occur through increased distributed surface roughness, through protruberances (e.g., a tripping wire), or by relying on free stream turbulence. Clearly, for very low Re, the boundary layer will always be laminar. A geometry relying on a few protruberances to trip the layer to turbulence may have some azimuthal dependence on gain. This angular dependence must be small to make the meter practical from a data-reduction standpoint.

Oscillatory flows provide another complication to boundary layer development. An unsteady boundary layer takes time to develop to its fully-separated condition. Consequently an oscillatory gain based on u_{max} may be different than the gain based on steady towing, depending on the Strouhal number ($S = fL/U$, where f = oscillation frequency, L is a characteristic length, and U is free stream velocity). Dynamic similarity in two unsteady flows requires equivalence of both Re and S for the different flows.

A combination of steady and unsteady flows will produce a complex, time-varying boundary layer around a sphere. The author knows of no numerical models which will accurately predict the boundary layer around a sphere for non-turbulent unseparated, non-turbulent separated, and turbulent flow conditions. As a result, the behavior of a current sensor can be evaluated only under carefully controlled laboratory conditions. Steady and oscillatory flow conditions can be measured independently of the meter to calibrate the sensor. The ambient turbulence level can be varied using screens or grids to generate turbulence on a variety of scales. Unfortunately, for many electromagnetic sensors the laboratory provides a noisy environment. A good facility must be relatively free from large external magnetic fields, either induced or direct. Even with precaution, the laboratory is not a true duplicate of field conditions. Rather, it provides a carefully controlled environment in which to assess current meter performance and error levels. This provides a basis for assessing field performance of the meters.

<u>Dimensional Analysis</u> -- Dimensional analysis can provide a convenient tool for evaluating sensor performance (Yalin (1972) provides a treatment of the technique). Dimensional analysis reduces a set of variables to a smaller group of dimensionless variables, against which system performance can be

assessed. These dimensionless groupings can be either rigorously determined, or more easily determined by trial-and-error and/or physical insight. Since some of the possible dimensionless groupings can be dependent, care must be taken to assure independence.

For steady flow, current meter output voltage is related to tow speed, current meter dimension, and viscosity of water. The dimensionless grouping from these parameters yields

$$\text{output voltage} = f({}^{Ud}/_{\nu})$$

For pure oscillatory motion, voltage is a function of amplitude of oscillation (A), period (T), current meter dimension (d), and water viscosity (ν). Possible dimensionless variables are

$${}^{A}/_{d},\ {}^{Ad}/_{\nu t}, \text{and } {}^{\nu T}/_{d^2}$$

Only two of these are necessary to describe the system. All three have physical significance. ${}^{A}/_{d}$ relates the unsteady ($^{\partial}/_{\partial t}$) to the convective terms ($U\ ^{\partial}/_{\partial x}$) in the governing equations. ${}^{Ad}/_{\nu T}$ is an unsteady Reynolds number, since $u_{max} = {}^{2\pi A}/_{T}$. ${}^{\nu T}/_{d^2}$ is the ratio of boundary layer thickness to current meter diameter.

For combined steady and oscillatory flow, output voltage = f(U, T, A, d, ν, θ), where θ is the angle between steady and oscillatory components. Possible dimensionless groupings include:

$${}^{UT}/_{A},\ {}^{\nu T}/_{d^2},\ {}^{Ad}/_{T\nu},\ {}^{Ud}/_{\nu},\ {}^{A}/_{d}, \text{and } \theta.$$

Four of these groups characterize the problem. Physical significance of these groups are the same as discussed earlier, with the addition of ${}^{UT}/_{A}$, an inverse Strouhal number.

The above dimensional analysis does not fully treat turbulent flows, ignoring scaling by friction velocity (U_*), roughness parameters (Z_0), and other terms with dynamical significance. When properly applied, the dimensional analysis provides a framework for evaluating sensor performance using terms with dynamical significance.

Representation of Results -- Analysis of calibration data has been in terms of Reynolds number (Re_s for steady flow and Re_0 for unsteady flow), Strouhal number for unsteady flow, and other dimensionless variables. Regression estimates were made for two models.

Model 1: $y = a + bx + \varepsilon$

where y = output voltage

x = dynamical or kinematic variable

a = offset

b = gain

ε = error term with zero mean and constant variance σ^2

Estimates of a and b, as well as the variance of those estimates, were made. Regression coefficients (r^2) and error variances were tabulated.

Model 2: $y_1 = a_1 + b_1 X + \varepsilon_1$ for $X \leq X_T$

$y_2 = a_2 + b_2 X + \varepsilon_2$ for $X > X_T$

This model separates the current meter response into two distinct regimes. Regression estimates for all variables (a_1, b_1, σ^2, σ_2^2, var (a_1), var (a_2), var (b_1), var (b_2)) were made and statistics generated for estimates of X_T.

RESULTS

Representative results from a single current meter are presented in Figures 1-6. Steady-flow and oscillatory-flow results are both depicted. Variations of gain as a function of different dynamical quantities are shown.

Results from these meters as well as others under examination should leave us with a more realistic idea of electromagnetic sensor performance under steady, oscillatory, or combined steady/oscillatory flows. These error estimates will be helpful when assessing the consistency of modeling results with field results. Similar analysis should accompany use of any sensor in the demanding nearshore environment.

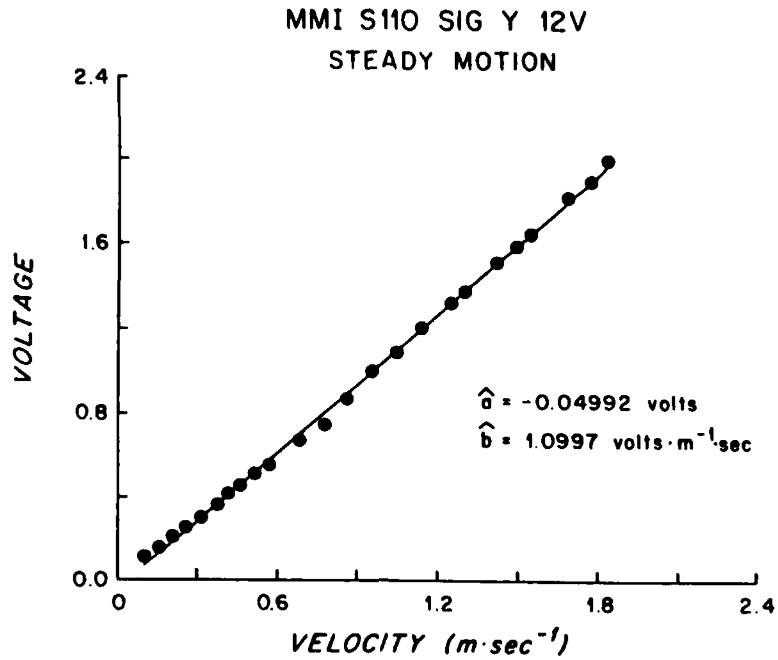

Figure 1. Steady-flow calibration for a 3.8-cm-diameter Marsh-McBirney 512/OEM current meter. a is the offset, b is the gain. Note the slope change near 0.6 m/sec. Abscissa is presented in terms of a kinematic variable (velocity) for clarity.

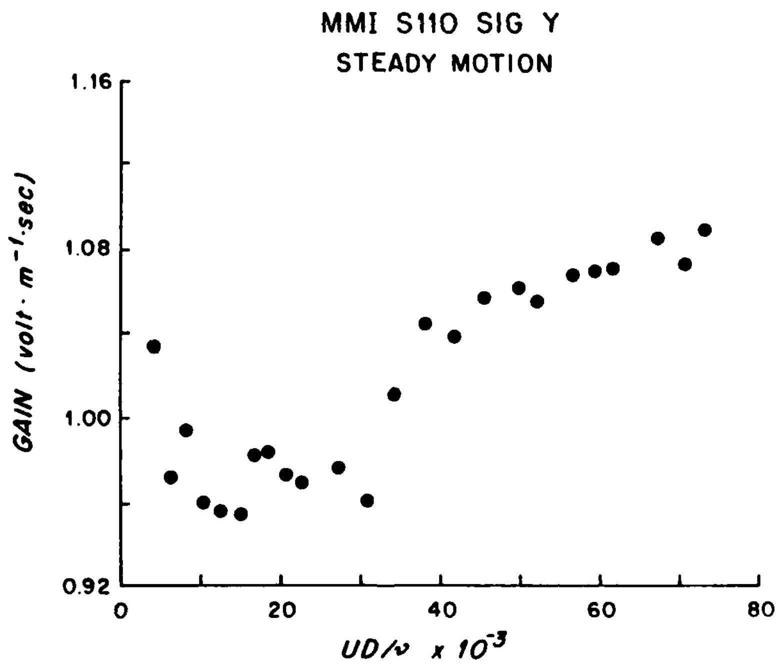

Figure 2. Gain as a function of Reynolds number for steady flow. Note change in gain at Re = 4 x 10^4, which suggests a transition at a lower Re than for a smooth sphere.

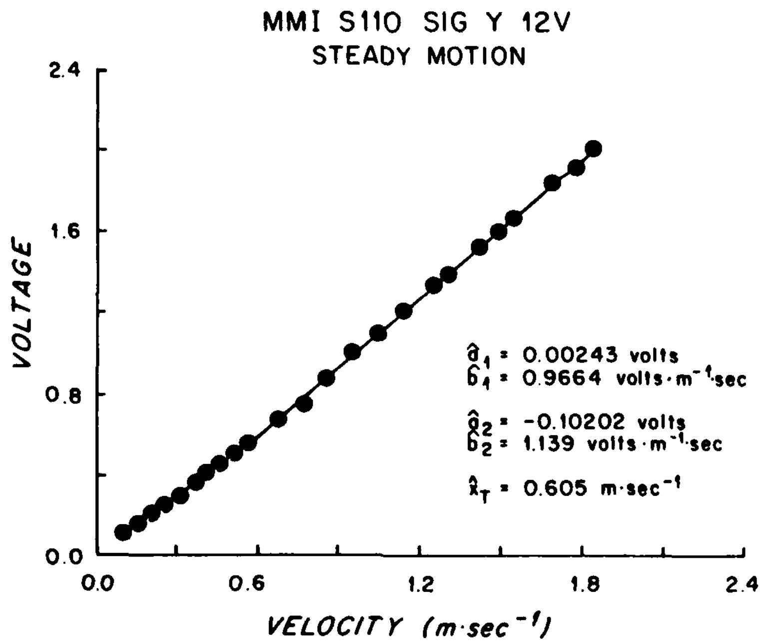

Figure 3. Steady calibration results using two best-fit lines to describe current meter response (velocity versus voltage). X_T is the intersection point which may be suggestive of a transition Reynolds number.

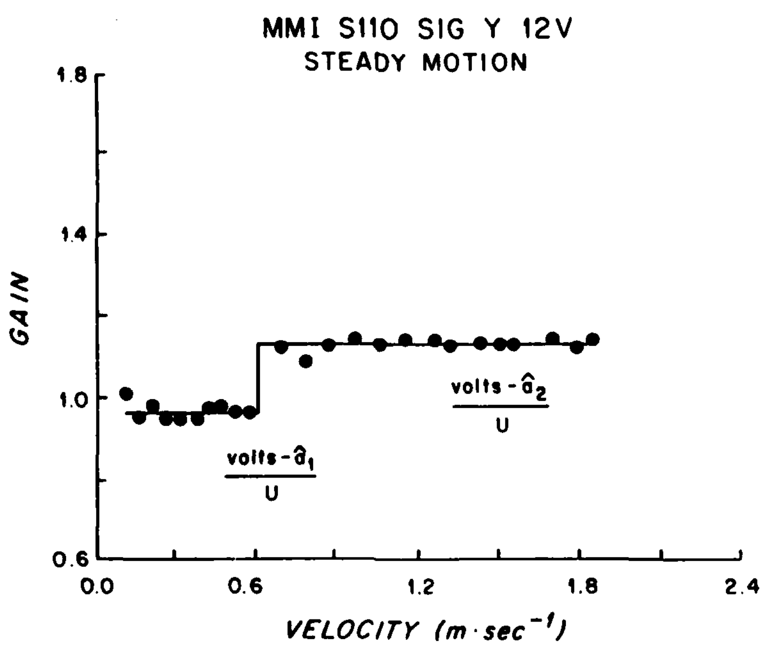

Figure 4. Gain versus velocity for the case described in Figure 3.

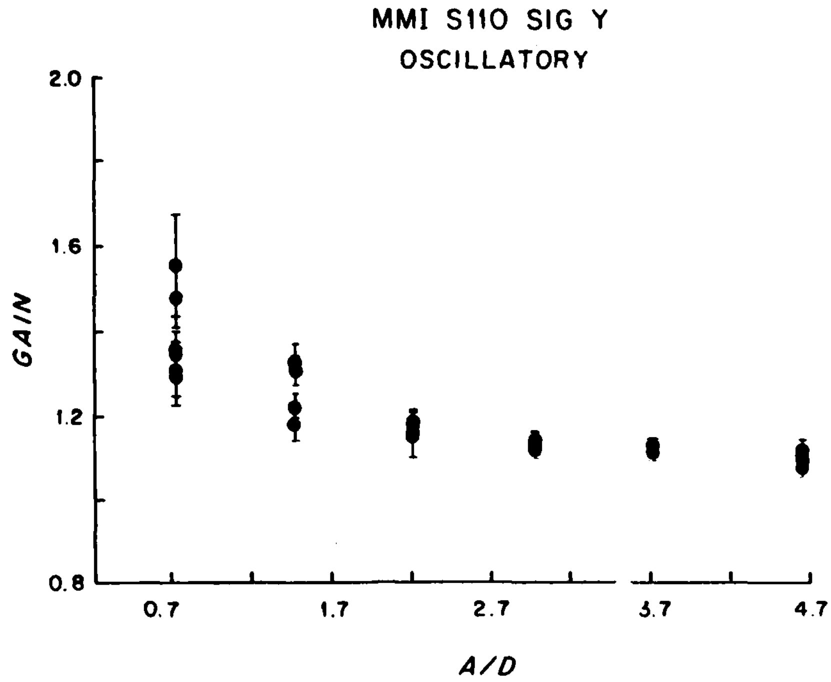

Figure 5. Oscillatory calibration plotted as gain versus $^{A}/D$. There is some unsteady dependence in the current meter gain.

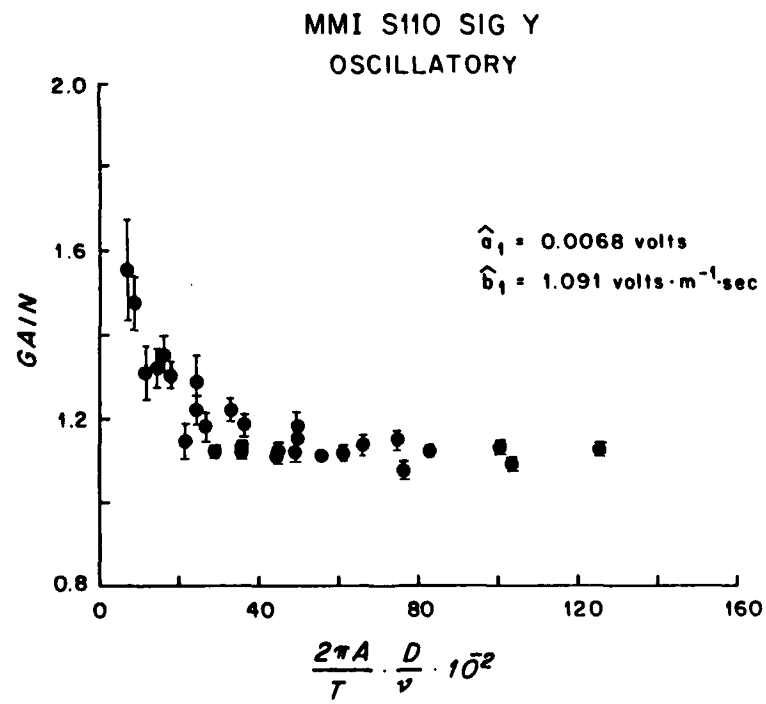

Figure 6. Oscillatory calibration plotted as gain versus unsteady Reynolds number. Gain varies about 30 over the range of Reynolds numbers examined, settling down at high Re to approximately the same gain as for steady flows.

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WIND-INDUCED NEARSHORE CURRENTS

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A 5-day record of current and wind was made nearshore in a depth of 8 m of water at the CERC Field Research Facility at Duck, N.C. The current record was processed to identify and remove components of motion other than wind-induced. Coherence between wind and current was examined. Hourly vectors of wind (10 m above sea surface) and resulting water motion at four levels from surface to 1 m above bottom will be shown in time-lapse fashion. There is indication that a model for this system requires a mechanism to describe initial water movement at onset of wind and a mechanism to describe changes as the system moves toward equilibrium.

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Finite Element Modeling of Nearshore Currents

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SUMMARY

Two finite element models for breaking wave-induced steady-state nearshore currents are presented. In the first model (Liu and Lennon, 1978), the nonlinear convective terms and the lateral diffusion terms are ignored. A transport stream function is introduced such that the continuity equation is satisfied automatically. Cross-differentiating the momentum equations, one derives a governing equation for the stream function, which is of the elliptic type. The flow domain is then discretized into linear triangular elements. Galerkin method is employed to convert the boundary value problem into an integral representation. The model is used to study the nearshore circulations over periodic topographies and localized irregular topographies. The primary advantage of using the finite element formulation is the flexible nature of the finite element layout; finer elements can be used near the breaker line and in the region of interest.

In the second model (Wu and Liu, 1982), both nonlinear convective terms and lateral diffusion terms are kept in the formulation. The continuity equation and momentum equations are solved directly for the current velocity and mean free surface set-up. The Galerkin method is again employed. Quadratic shape functions are used for the velocity components, and linear shape functions are used for the mean free surface set-up. The resulting system of simultaneous

equations for unknown variables is nonlinear. Converged solutions are obtained by using the method of successive substitution. The accuracy of the model has been verified by comparing results with analytical solutions for longshore currents and rip currents. Results are also shown for the meandering current pattern corresponding to skewed rip current channels. The importance of the nonlinear convective effects is demonstrated.

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FINITE DIFFERENCE MODELING OF NEARSHORE CIRCULATION

by

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In this presentation, the numerical nearshore circulation models developed by Birkemeier and Dalrymple (1976) and Ebersole and Dalrymple (1979) were reviewed, and an attempted calibration using field data from the NSTS Torrey Pines experiment (Gable, 1979) was discussed.

Theoretical Formulation of the Models

The circulation models solve finite difference forms of the depth and time-averaged equations of continuity and momentum (see, for example, Phillips (1977), sec. 3.6), with local wave height and wave angle calculated by the method of Noda et al. (1974), including wave-current interaction. The formulation of Birkemeier and Dalrymple is linear in the velocity field, neglecting the effects of convective acceleration. The stress formulation is also linear in the mean current. The more recent model of Ebersole and Dalrymple includes the effect of convective accelerations and lateral mixing and formulates the bottom shear stress using the method of Liu and Dalrymple (1978). Both models allow for the effect of a wind stress on the current distribution.

Numerical Solution Methods

Both circulation models are finite-differenced in explicit, time-dependent form. The linear model is discretized using simple forward space-forward time derivatives. The algorithm for the nonlinear model is a three-time-level leap-frog scheme developed by Lilly (1965) for application to meteorological problems. Both models have been found to require maximum time steps which are significantly lower than the Courant number corresponding to the formulations. During a model run, the wave field is periodically updated; wave-current interaction is thus fully implemented by both models.

Both models incorporate a no-flow offshore boundary condition, which causes some seiching at model start-up. This effect is reduced by gradually increasing

the incident wave height up to its steady value. Both models assume longshore periodicity in bottom topography and currents. The grid scheme is uniformly rectangular, with different spacings allowed in the longshore and on-offshore directions.

Model Calibration

An attempt has been made to calibrate the models using data from the NSTS Torrey Pines experiment. The Torrey Pines bathymetry consists of uniform shore-parallel contours and is ideally suited to model application. However, the wave climate during the test period was usually bimodal, with directional spectral peaks arriving from both offshore quadrants. It was found that, by using a sum of the r.m.s. spectral density and a weighted average of the corresponding directions, it was possible to model the measured field longshore current distribution reasonably well; however, the field conditions violate the model requirement of a monochromatic incident wave. Values for the bottom friction coefficient were found to be of the order of 0.002, which is lower than would normally be expected. Details of the calibration as well as the model development can be found in Kirby and Dalrymple (1982).

Conclusions and Future Plans

The models developed to date provide stable computational schemes for predicting wave-induced circulation. The models are somewhat expensive in a computational sense due to the explicit differencing schemes and the resulting excessive number of iterations required to obtain steady-state solutions. However, the model of Ebersole and Dalrymple successfully implements full wave-current interaction and bottom friction schemes which have not been incorporated in several of the computationally faster models, to date.

The obvious choice for future improvement rests in incorporating an implicit computational scheme in order to minimize computational time. In addition, it is planned to replace the refraction scheme of Noda with a refraction-diffraction model based on the work of Booij (1981), which would allow for the modelling of wave interactions with coastal structures.

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Turbulent Transport Model for Nearshore Environment

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Turbulent transport plays an important role in various dynamic processes in the nearshore environment; e.g., resuspension and transport of sediment; wave breaking; and vertical transfer of momentum, heat, and sediment. Outside the surf zone, wave orbital motion interacts with current driven by tide, wind, or density gradient (Sheng and Butler, 1982; Sheng and Lewellen, 1982). Inside the surf zone, resuspension of sediment is caused by the interaction between wave orbital motion and longshore current.

Due to the lack of quantitative understanding, however, turbulent transport in the nearshore environment has been generally parameterized by eddy viscosity models. Although this permits simple closure of the equations of motion, eddy viscosity models are often inadequate for simulating complex flow situations because of two major deficiencies. First of all, due to their empirical nature, eddy viscosity models require a large data base to establish the validity of the model parameters for each new application. If sufficient data are not available and the required parameters for a specific application must be extrapolated from very different situations, the resulting predictions are highly speculative. Secondly, eddy viscosity models do not contain the accurate physics describing the oscillatory and stratified flow situations often encountered in the nearshore environment. For instance, eddy viscosity models cannot account for the time lag between the turbulent transport and the mean flow gradients or the counter-gradient turbulent transport due to unstable density gradients.

This presentation highlights a turbulent transport model developed to make accurate predictions in turbulent flows where data is unavailable or hard to obtain, using as its strength modeling constants evaluated in situations far removed from the flow of application. The basic turbulent transport model, originally developed by Donaldson and his associates at A.R.A.P. (e.g., Donaldson, 1973; Lewellen and Sheng, 1980a and b; Lewellen, 1981; Sheng and Lewellen, 1982,), involves the retention of the second-order turbulent correlation equations that affect the mean flow variables. Models are developed for the unresolved third-order correlations appearing in these equations. Model constants are derived from analyzing a wide class of flow situations and remain invariant for new applications. Critical flow experiments, in which only one of the model constants is important, are used as much as is possible. The added physics contained in the second-order closure model permit one to directly calculate the phenomena mentioned in the previous paragraph, without resorting to some ad hoc eddy viscosity fixes.

Four example applications of the turbulent transport model are given: (1) an oscillatory turbulent boundary layer; (2) the transport of momentum, heat, and species within a vegetation canopy; (3) current-wave interaction within the bottom boundary layer; and (4) upper ocean mixed-layer dynamics.

For the first example, the turbulent transport model was used to simulate Jonsson and Carlsen's (1976) laboratory experiment on oscillatory turbulent boundary layer. Model results compare favorably with Jonsson and Carlsen's data for the mean velocity profiles, the shear stresses, and the phase relationships (Sheng, 1982). In addition, the model was able to predict the time-dependent behavior of the very thin logarithmic layer near the bottom.

The second example deals with turbulent flow over vegetation canopies which are often encountered in coastal and atmospheric environments. Interactions between the canopy and the turbulent flow are incorporated into the model by partitioning the total drag into a skin friction drag and a profile drag, and by introducing various source-and-sink terms into the conservation equations. Model predictions agree closely with the measured Reynolds stresses, mean velocities, standard deviations, and heat transfer rate obtained by Wilson and Shaw (1977) in a corn canopy.

The third example is the current-wave interaction within the bottom boundary layer. Model predictions are compared with ocean bottom boundary data obtained in the CODE program (Sheng and Lewellen, 1982). Recent laboratory studies have indicated that the presence of the wave may either enhance or reduce the Reynolds stresses due to the mean flow. Primarily due to the interaction between the wave and the turbulent eddies, this phenomenon can be simulated with the turbulent transport model but not with an eddy viscosity model.

The fourth example is the simulation of the ocean mixed-layer dynamics based on data from the MILE experiment (Davis et al. 1981). Despite the great variability of the ocean wind and surface heating during the 32-day period, the evolution of the thermocline and the time variation of the surface temperature are accurately simulated.

In summary, a turbulent transport model is available to provide accurate simulation of the various complex flow situations often encountered in the nearshore environment. Despite its relatively more complex mathematical formulation over eddy-viscosity models, the turbulent transport model can provide definitive, quantitative understanding of the turbulent transport processes and hence should be applied to a wide variety of nearshore circulation and sediment studies.

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Numerical Calculations of Waves in Shallow Water

by

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This paper summarizes the development of an analytical/numerical model describing the evolution of water-wave disturbances in shallow water. The model extends a Boussinesq-type model by one order when nonlinear and dispersive parameters are in approximate balance, and by three orders in a dispersive parameter when nonlinearities are small. At present, the model accommodates gradual changes in channel breadth and can be easily extended to accommodate changes of depth. The surface elevation and fluid velocity at the bottom are time-stepped explicitly, with central space and time differencing. A high-order expansion is used to connect the time-stepped variables (surface elevation and x-derivative of a surface velocity potential) to other variables entering the formulation, such as volume flux and surface velocities.

Sample numerical calculations verify that the model has the following properties:

1. It represents solitary waves more accurately than second-order time-independent theories,

2. It recovers certain qualitative features observed in laboratory experiments that had not before received theoretical/numerical explanation,

and

3. It is reversible, in that a reversal $dt \to -dt$ imposed at time $T/2$ recovers initial conditions at T.

The model employs large time steps ($\Delta t = \Delta x$, in dimensionless units), so that it is relatively inexpensive to run for long times.

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